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JESS 1.1 AIR DEFENSE ARTILLERY (ADA) VALIDATION REPORT

Fort Leavenworth

U.S. ARMY
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TRAINING SIMULATIONS DIRECTORATE
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TRADOC Analysis Command-Fort Leavenworth (TRAC-FLVN)
Training Simulations Directorate
Fort Leavenworth, Kansas 66027-5200

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A validation was conducted on the air defense artillery (ADA) section of the Joint Exercise Support System (JESS) model version 1.1. As a result of this study, we recommend that JESS 1.1 ADA not be accepted as valid.

The data base contains weapon characteristic values that are producing invalid results. The Pk values for the ADA systems need to be degraded and the rounds per burst for the guns need to be decreased.

Errors in the JESS 1.1 code are also producing invalid results.

1. The range degradation factors for ADA weapons are not being correctly applied. Consequently, long-range ADA weapons are allowed to fire at aircraft flying nap of earth (NOE).

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2. Helicopters flying at NOE are more vulnerable than helicopters flying at 200 feet above ground level.

3. The definition of altitude band boundaries in the data base is not consistent with the code logic used to determine the altitude band and used to select the Pk which is dependent upon altitude. This results in erroneous data being supplied to the data base. Providing some consistency in the definition of these altitude bands would aid the people who supply Pk data based upon aircraft altitude.

4. The code allows aircraft to fly below ground level. This results in negative training and unintended protection to aircraft since ADA weapons will not fire at aircraft flying below a minimum altitude.

The results from the JESS 1.1 ADA tests were compared to a benchmark set of ADA results obtained from the Vector-in-Commander (VIC) model. A previous report entitled Technical Memorandum TRAC-F-TM-1388 JESS 1.0 Air Defense Artillery (ADA) Validation, published in October 1988, describes how this benchmark was developed.

Sensitivity tests were conducted on the JESS 1.1 ADA module to determine the effect of changing mission type and size, altitude, number of weapons, aircraft type, range and Pk of weapon, and number of rounds per burst on attrition.

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ABSTRACT

A validation was conducted on the air defense artillery (ADA) section of the Joint Exercise Support System (JESS) model version 1.1. As a result of this study, we recommend that JESS 1.1 ADA not be accepted as valid.

The data base contains weapon characteristic values that are producing invalid results. The Pk values for the ADA systems need to be degraded and the rounds per burst for the guns need to be decreased.

Errors in the JESS 1.1 code are also producing invalid results.

1. The range degradation factors for ADA weapons are not being correctly applied. Consequently, long-range ADA weapons are allowed to fire at aircraft flying nap of earth (NOE).

2. Helicopters flying at NOE are more vulnerable than helicopters flying at 200 feet above ground level.

3. The definition of altitude band boundaries in the data base is not consistent with the code logic used to determine the altitude band and used to select the Pk which is dependent upon altitude. This results in erroneous data being supplied to the data base. Providing some consistency in the definition of these altitude bands would aid the people who supply Pk data based upon aircraft altitude.

4. The code allows aircraft to fly below ground level. This results in negative training and unintended protection to aircraft since ADA weapons will not fire at aircraft flying below a minimum altitude. (SLW)

The results from the JESS 1.1 ADA tests were compared to a benchmark set of ADA results obtained from the Vector-in-Commander (VIC) model. A previous report entitled Technical Memorandum TRAC-F-TM-1388 JESS 1.0 Air Defense Artillery (ADA) Validation, published in October 1988, describes how this benchmark was developed.

Sensitivity tests were conducted on the JESS 1.1 ADA module to determine the effect of changing mission type and size, altitude, number of weapons, aircraft type, range and Pk of weapon, and number of rounds per burst on attrition.

1. Purpose. This report presents the results of the December 1988 validation tests performed on the air defense artillery (ADA) play in the Joint Exercise Support System (JESS) 1.1. The purpose of this testing was to compare the results from JESS 1.1 to results in a previously published run, Technical Memorandum TRAC-F-TM-1388, October 1988, entitled JESS 1.0 Air Defense Artillery (ADA) Validation. This classified memorandum contains results from JESS 1.0 air defense play and the Vector-In-Commander (VIC) 6.3 excursion run which was used as a benchmark to judge the validation of the JESS 1.0 results. These VIC results were also used to judge the results from our December tests on JESS 1.1. The results from this analysis will be presented to the JESS configuration control board and other users.

2. Problem. Several changes have been made to the JESS 1.0 version of the air defense module in JESS 1.1. We felt it was necessary to repeat the validation testing that had been done on JESS 1.0 to determine the significance of these changes.

a. In JESS 1.0, helicopters were modeled the same as fixed-wing aircraft. In JESS 1.1, helicopters are modeled separately from fixed-wing aircraft. Orders for helicopter missions are processed under the army aviation menu which is different from a fixed-wing order menu, and ADA damage reports for helicopters are processed separately from fixed-wing damage reports.

b. A new table of data was added to JESS 1.1 to allow for range degradation of ADA weapons, depending upon the aircraft's altitude. This table of degradation factors reduces the lethal range of some ADA weapons to zero if the aircraft is flying nap of earth (NOE) altitude.

c. Lastly, we learned that the Jet Propulsion Laboratory (JPL) had rewritten the code that calculates the number of rounds fired per salvo. In JESS 1.0, the number of rounds fired per salvo depended upon the number of weapon systems in the ADA unit. If a unit had six Hawks, six shots would be fired for each salvo. We were told this methodology had been changed. For missiles, the number of shots fired is dependent upon a value assigned in the data base to that weapon system. For guns, the old methodology still applies (i.e., one burst times the number of guns in the unit for each salvo fired).

3. Objectives. Our objectives were threefold.

a. To determine what impact the above changes had upon ADA attrition results compared to ADA play in JESS 1.0.

b. To compare the results from JESS 1.1 to the VIC benchmark results (previously published in Technical Memorandum TRAC-F-TM 1388, October 1988).

c. To conduct sensitivity tests on both gamer input variables and data base variables such as weapon range and rounds per burst.

4. Limitations. The aircraft and ADA weapons tested were limited to those which are common to the VIC 6.3 excursion benchmark and JESS 1.1, with the exception of the Vulcan which is not played in VIC. This analysis did not include synergistic effects on ADA units by other combat units. The units in the analysis were composed of only one type of ADA weapon system. Only close air support (CAS) and battlefield air interdiction (BAI) missions were tested in this analysis. Our tests were confined to the two lower altitude bands (0 to 490 and 490 to 4,900 feet). No air corridor protection to missions was provided in our tests. The tests were structured so no attrition of ADA units occurred from enemy fire during our tests.

5. Assumptions.

a. The ADA unit configurations in VIC excursion 6.3 are correct and acceptable for our analysis.

b. The VIC ADA results from the Europe 6.3 base case presented in the JESS 1.0 ADA Validation Report (TRAC-F-TM-1388) are acceptable for use as a benchmark in this analysis.

6. Constraints. Analysis of the ADA module of JESS 1.1 was subject to the same general constraints as the analysis of the other modules. Source code was not available. We used the Software Design and Documentation Language (SDDL) code for this analysis.

7. Methodology. For this analysis a data base was constructed containing ADA units composed of only one type of ADA weapon system and the radars associated with that system. The number of weapon systems in the unit was the same as the number in the benchmark VIC run. The ADA units were located far enough from each other to prevent more than one ADA unit firing at a mission. Each air mission or army aviation mission was assigned an ADA unit as a target to make sure the mission flew dead center over the ADA unit. The air missions were given minimal munitions to fire to avoid degradation to the target ADA unit. Each air mission or army aviation mission was replicated 10 times to obtain an average result. Some tests were repeated an additional 10 times to test the effect of sample size on the results.

a. Related studies. JESS 1.0 Air Defense Artillery (ADA) Validation (TRAC-F-TM-1388), October 1988.

b. Essential elements of analysis (EEA) and measures of effectiveness (MOE).

(1) EEA. The following EEA were used to determine what results were needed in the analysis:

(a) How does attrition of aircraft in JESS 1.1 compare with attrition of aircraft in VIC and in JESS 1.0.

(b) In an engagement, over what range does attrition to aircraft occur?

(c) How many shots are fired by the ADA unit in an engagement?

(d) How successful are ADA units in detecting air missions?

(2) The MOE used in the analysis were as follows:

(a) What is the average number of aircraft killed in an engagement with each ADA unit (expressed as percent of total aircraft flown)?

(b) What is the average number of aircraft hit in each ADA engagement?

(c) What is the minimum and maximum number of aircraft hit in an engagement with each ADA unit?

(d) What is the average number of shots fired per engagement?

(e) What is the average percent of air missions detected by the radar units?

(f) What is the minimum and maximum range of detection for each set of 10 samples?

(g) What is the minimum and maximum range the ADA weapon fires for each set of ten samples?

c. Method of analysis. The following aircraft were used in the tests: A-10, F-16, AH-64, Frogfoot, and Hind. The following ADA weapons were used in the tests: Patriot, Hawk, Chaparral, Stinger, Vulcan, SA-11, SA-13, SA-14, and ZSU 23-4. Air missions contained two aircraft per mission, except in sensitivity tests designed to test the effect of mission size on attrition from ADA. Army aviation missions contained four aircraft per mission except in sensitivity tests designed to test the effect of mission size on attrition from ADA. The base case in this analysis consists of 15 tests. Nine of these tested fixed-wing aircraft against nine different ADA weapon systems; six tested helicopters against six different ADA weapon systems. Sensitivity tests were run to determine the effect of changing the mission parameters or the ADA weapon characteristics. The sensitivity runs included the following:

(1) Effect of mission type (BAI or CAS).

(2) Effect of mission size.

(3) Effect of aircraft altitude.

(4) Effect of number of weapon systems in the ADA unit.

(5) Effect of aircraft type (F-16 versus A-10).

(6) Effect of changing the range of an ADA weapon.

(7) Effect of changing the number of rounds per burst of an ADA weapon.

(8) Effect of changing the probability of kill (Pk) of the ADA weapon.

8. Results. First, to establish that a sample size of 10 was sufficient for determining the average number of aircraft killed and hit, we ran three tests with a sample size of 20 missions and compared the results to a 10-sample test run. The results are in table 1. The results show at most a 10 percent difference between a sample size of 10 and 20 in the number of hits for a Stinger. We accepted this range in results and opted to use the smaller sample size of 10 for our tests. This allowed us to increase the number of sensitivity test runs, given our limited resources.

Table 1. Effect of sample size on attrition results

ADA vs. mission	Sample size	% hit
SA-14 vs. AH-64	10	23
	20	21
Stinger vs. Frogfoot	10	25
	20	28
Stinger vs. Hind	10	58
	20	56

a. Base-case attrition results. Tables 2 and 3 list the results from running the test matrix with respect to average percent of aircraft killed and hit in the army aviation and fixed-wing aircraft tests. The tables list the weapon, the mission flown against the ADA weapon type, the average percent of aircraft killed, the average percent of aircraft hit, the minimum number hit in any one mission, the maximum number hit in any one mission, and the average number of rounds fired at the mission by the ADA unit. These averages were found by dividing the total number of aircraft hit or killed over 10 missions by the total number of aircraft flown in 10 missions. The tables list the killers of aircraft in descending order of lethality sorted by side (Red, Blue) and similar test parameters (NOE, 200 feet, eight helicopters, etc.)

(1) In two ranking cases, the number of aircraft hit was used to break a tie between weapon systems with approximately equal kills. In table 2, the SA-11 and SA-13 had equal kills but varied significantly in the number hit. In table 3, the Chaparral and Vulcan killed approximately the same number of aircraft but varied significantly in the number hit.

(2) The minimum and maximum number hit and the average number of shots fired per engagement were used to help determine if the differences in number hit or killed were significant. An engagement is defined as the total number of salvos fired at the mission while it is within range of the ADA unit.

(3) When an aircraft is hit, a random draw is made to determine if the hit aircraft has been killed or just damaged. Each aircraft type has a probability of damage value assigned to it in the data base. Damaged aircraft return to the base for repair and can re-enter the game after repairs. Repair time is determined by a random draw and varies from a few hours to infinity (these aircraft are not repairable). Damaged aircraft immediately drop out of the mission and return to base. They do not attempt to deliver ordnance. From that particular mission's viewpoint, a damaged aircraft does not contribute any more to the mission than a killed aircraft. A damaged aircraft can be shot again by the ADA unit if it is within range of the weapon but only if there are no other undamaged aircraft to shoot at. Once a damaged aircraft is hit again, it becomes a killed aircraft. It is possible to hit a mission with four aircraft more than four times if the hits result in damage and not kills.

(a) Army aviation. The results from table 2 show that comparable Red and Blue ADA weapons are not comparably hitting or killing helicopter targets. The Stinger is comparable to the SA-14, yet the results show the Stinger is twice as lethal as the SA-14 in killing helicopters. The ZSU-23-4 and the Vulcan are comparable weapons. They hit about the same number of helicopters flying NOE. The Chaparral, SA-11, and SA-13 are not supposed to be able to shoot at helicopters flying NOE if the game is correctly using the range degrader bands in the data base. The results in table 2 show these systems are major killers of helicopters flying NOE.

Table 2. Helicopter ADA results from JESS 1.1

Weapon vs. tgt	Ave. % killed	Ave. % hit	Min no. hit	Max no. hit	Ave no. rds.
Red ADA vs.					
4 AH-64 NOE					
ZSU-23-4	52	95	4	5	4000.0
SA-11	25	50	0	2	14.6
SA-13	25	40	0	4	9.5
SA-14	13	23	0	2	8.1
4 AH-64 200 ft.					
SA-14	9	16	0	1	4.0
8 AH-64 NOE					
SA-14	11	19	0	3	8.5
Blue ADA vs.					
4 Hind NOE					
Chaparral	75	100	3	6	16.1
Vulcan	58	83	2	4	3240.0
Stinger	30	55	0	4	8.5
4 Hind 200 ft.					
Chaparral	29	46	0	3	7.3
Vulcan	25	40	1	2	2160.0
Stinger	15	30	0	3	4.8

(b) Fixed-wing aircraft. Table 3 presents the results from our fixed-wing aircraft tests. With the exception of the ZSU-23-4, the Blue ADA weapons are all more lethal than their Red counterparts. Fixed-wing analysis has previously been performed on JESS 1.0. However, there are some differences between the performance of ADA in JESS 1.0 and in JESS 1.1. The Patriot, Chaparral, Stinger, and SA-14 are performing the same in JESS 1.1 as in JESS 1.0. The Hawk, SA-11, SA-13, ZSU-23-4, and Vulcan are killing at a higher rate in JESS 1.1 compared to JESS 1.0. We attribute these higher kill rates to changes made to the JESS 1.1 Pk values in the data base. (These Pk values are actually probability of hit values, but they are called Pk values in the JESS 1.1 data base. We will refer to them as Pk values to remain consistent with JESS nomenclature).

b. Comparing the benchmark results from the VIC 6.3 excursion to the JESS 1.1 ADA results for fixed-wing aircraft revealed the following:

(1) Hawk, Chaparral, Stinger, SA-11, ZSU-23-4, and Vulcan are hitting and killing fixed wing at higher rates than expected. These weapons are two to three times more lethal in JESS 1.1 than the benchmark results.

Table 3. Fixed-wing ADA results from JESS 1.1

Weapon vs. tgt	Ave. % killed	Ave. % hit	Min. no. hit	Max. no. hit	Ave. no. rds.
Red ADA vs.					
2 A-10 CAS 200 ft.					
SA-11	40	75	0	2	15.1
ZSU-23-4	27	50	0	1	800
SA-13	15	20	0	2	2
SA-14	5	10	0	1	2
2 A-10 BAI 200 ft.					
SA-11	20	85	0	2	14.4
2 A-10 CAS 50 ft.					
SA-13	0	15	0	1	2
2 F-16 BAI 200 ft.					
SA-11	35	40	0	2	10.8
ZSU-23-4	15	45	0	1	800
SA-13	5	10	0	2	2
SA-14	0	3	0	1	1.8
Blue ADA vs.					
2 Frogfoot CAS 200 ft.					
Patriot	70	100	2	3	4.5
Hawk	65	100	2	3	3.5
Chaparral	25	55	0	2	2.2
Vulcan	28	40	0	1	1080
Stinger	20	30	0	2	1.8
2 Frogfoot BAI 200 ft.					
Hawk	75	100	2	3	3.5
4 Frogfoot BAI 200 ft.					
Hawk	30	63	1	4	5.4
10 Frogfoot CAS 200 ft.					
Chaparral	5	10	0	2	2.2
2 Frogfoot CAS 500 ft.					
Stinger	25	25	0	2	2
2 Frogfoot CAS 1000 ft.					
Hawk	70	95	1	3	4.2
2 Frogfoot CAS 200 ft.					
Hawk.3	55	80	0	3	4.7
Sting.3	14	19	0	1	1.6

(2) Patriot, SA-13, and SA-14 are killing fixed wing according to what is expected from the benchmark results. Vulcan was not played in the VIC 6.3 study, but, assuming it performs comparably to the ZSU-23-4, we concluded its kills were also too high.

c. The average number of shots fired per engagement. The last column in tables 2 and 3 lists the average number of shots fired by the ADA unit per engagement. These averages are calculated from the 10 repetitions for each ADA test. An engagement by the ADA unit can be several salvos, depending upon how long the air mission is within range of the ADA unit. Length of time the air mission is within range of the ADA unit depends upon the air mission's speed, the range of the ADA unit, and the location of the air mission's path across the ADA unit's lethal envelope.

d. The average percentage of air missions detected by the radar unit.

(1) Army aviation. In JESS the term detection as it appears on the ADA spot reports, refers to detection by radar. An enemy target can be detected visually and shot at by unit X but the spot report will read, "Unit X shot at an undetected enemy mission." Detection by radar was not a significant factor in our helicopter tests since the ADA weapons we tested could rely upon visual detection. The range for visual detection in JESS is eight kilometers (km). Effects of terrain background on weapons are not modeled in JESS.

(a) If an Airborne Warning and Control System (AWACS) detected an enemy mission this information was immediately passed to all ADA units. An AWACS mission always detected enemy helicopter missions, even at NOE altitude. This can be changed via a data base value called mean.time.to.detect. A value is entered for each type of aircraft. Setting this value very high eliminates detection by AWACS.

(b) In the case of Stinger, SA-14, Vulcan, and ZSU-23-4, predetection by a radar unit had no effect on the attrition caused by the ADA unit. Visual detection was approximately 90 percent. If the aircraft flew within eight km of the ADA Stinger unit, it was fired upon nine out of ten times.

(2) Fixed wing. If an AWACS mission was on station all enemy fixed-wing aircraft were always detected. If no AWACS were up, the SA-13 and Chaparral could visually detect enemy aircraft and fire upon targets that were flying below 200 feet, but the Hawk, Patriot, and SA-11 could not detect nor fire upon enemy aircraft flying below 200 feet mean sea level (MSL) with their radar, nor could they visually acquire the target. An AWACS had to be orbiting for the Hawk, Patriot, and SA-11 to detect and shoot at targets flying below 200 feet MSL. Even when the Hawk unit had been attacked by enemy aircraft, the Hawk would not

shoot unless an AWACS had detected the mission. The radars for these long-range systems have minimum detection altitudes in the data base that prevent detection below 0.1 km. Detection by AWACS was 100 percent. Detection by radar without an AWACS was about 90 percent for the Chaparral and SA-13, but these weapons could also rely upon visual detection.

e. What were the minimum and maximum ranges of detection for our 10 samples? The radar detection ranges in the data base were checked against the ranges calculated from knowing the aircraft location when it was detected and the location of the detecting ADA unit. The radar values were always within the range limits set by the data base values.

(1) If the aircraft were flying at 500 feet MSL, the Hawk radars could detect them no farther than 50 km away. The aircraft were usually detected at the farthest edge of the ADA radar's detection envelope. The Hawk radar usually detected the missions when they were 40 to 50 km away.

(2) Detection of the enemy unit by AWACS occurred as soon as the air mission took off from the airbase. The data base value for range of detection by AWACS is set at 500 km.

(3) It was not possible to identify the point at which visual detection occurred. We assumed if the ADA unit fired, it had detected the mission. We could track location at the time of firing by the ADA unit for helicopter missions only. These firing range distances were always less than the eight km visual range of the weapon.

f. What were the minimum and maximum ranges of fire for our 10 samples? Table 4 lists the minimum and maximum ranges from which the ADA weapons were noted to have fired. Unfortunately, we could only determine firing ranges from army aviation test results as their spot reports are the only ones that gave universal transverse mercator (grid) (UTM) locations of the aircraft when it was engaged. In the case of fixed-wing aircraft, no UTM coordinates were given. This is another difference between JESS 1.1 and JESS 1.0. In the older version, the UTM coordinates of the plane were given when it was shot.

Table 4. Recorded firing ranges for Red and Blue ADA

ADA vs. Mission	Max. (km)	Min. (km)	Average (km)
Stinger vs. Hind at NOE	6.5	0.7	3.0
Chaparral vs. Hind at NOE	5.7	1.1	3.4
Vulcan vs. Hind at NOE	0.5	0.1	0.3
ZSU-23-4 vs. AH-64 at NOE	4.0	0.2	1.8
SA-13 vs. AH-64 at NOE	5.5	0.1	3.3
SA-11 vs. AH-64 at NOE	30.0	0.5	15.0
SA-14 vs. AH-64 at NOE	5.5	0.5	2.7

(1) From the ranges we determined through the army aviation reports, we found that all but the ZSU-23-4 were less than or equal to the ranges given in the data base for the maximum effective range of the weapon. The ZSU-23-4 should not fire beyond a range of 2.5 km but did fire at a helicopter mission placed at a four km standoff range from the ZSU ADA unit. We have no explanation for this occurrence.

(2) We found the game was not using the correct range degrader factors for very low altitude bands. The range of the SA-11 and the SA-13 is supposed to be zero if the aircraft is flying NOE. However, we found the SA-13 could shoot AH-64 flying NOE at a range of seven km. We also found an SA-11 could shoot an AH-64 flying NOE at a range of 30 km. Later conversations with personnel at JPL confirmed the first release of the code had a problem reading the range degradation factors. We also found an error in the range degrader parameter in the data base. The SA-14 and SA-7 firing against aircraft flying NOE should be degraded about as much as a Stinger firing against aircraft flying NOE. The Red weapons are degraded to 0.08 of their original data base value while the Blue weapons are degraded to 0.8 of their original value.

g. Other needed changes are as follows:.

(1) The fixed-wing aircraft sometimes were reported flying at negative altitudes, putting them below ground level. This occurred because the mission orders for flying altitude are input as MSL altitudes. The spot detection reports give the above-ground-level altitudes of the aircraft. No penalty is assessed in the game for flying at a negative altitude because the lowest ADA altitude band in the data base ranges from negative infinity to plus 490 feet. Aircraft may be at an advantage flying below ground, because the range degrader bands work on above-ground altitudes and the ADA weapon range may be shortened to zero if the aircraft is flying at or below NOE altitudes.

(2) We also discovered an unexpected effect on helicopter attrition caused by the gamer's method of inputting the mission order. Taking a Red helicopter mission as an example, two points were specified for an ingress route, starting with the helicopter base and ending with the target, and two points were specified for the egress route, starting with the target location and ending with the helicopter base location. The mission took 20 minutes to arrive at the target and only three Stingers fired at the mission. If only the target location was input in the ingress menu and only the helicopter base location was input in the egress menu, the time to arrive on station was 83 minutes, and the Stinger fired nine rounds at the mission. Furthermore, we discovered that if we reversed the single points specified in the ingress and egress menu so that helicopter base location was input in the ingress menu and target location was input in the

egress menu, the attrition and time to arrival reverted to that obtained from specifying the two points for ingress and two points for egress. The result of this code error is that some missions were entirely destroyed due to the gamers' input procedure.

9. Sensitivity analysis. Tables on page 7 presents results from changing the mission type, the mission size, the mission altitude, the number of weapons per ADA unit, and the type of aircraft. Table 2, page 6, presents results from changing the helicopter mission size.

a. Effect of mission type. We did not discern a significant difference in results due to whether the fixed-wing mission was a CAS or BAI mission. Table 3 shows small differences in the number hit when Hawk fires at a Frogfoot mission flying CAS or BAI. The average number of rounds fired per engagement and the maximum and minimum number of aircraft hit were the same for both CAS and BAI missions for the Hawk. The average number of aircraft killed in the SA-11 tests for CAS vs. BAI is disturbingly different. We attribute this difference to the randomness in the damage or kill determination once the aircraft is hit and not to the fact that a mission was flying CAS or BAI. We have found nothing in the SDDL code or the data base to indicate there should be a difference in attrition depending on whether a CAS or BAI mission is ordered by the gamer.

b. Effect of mission size.

(1) Increasing the size of our helicopter mission from four AH-64 to eight AH-64 results in a larger number of helicopters killed by SA-14 (see table 2). The percent killed by SA-14 remained approximately the same, but doubling the number of helicopters in the mission means the number of helicopters killed was doubled compared to the number killed in the mission with four helicopters.

(2) Increasing the number of Frogfoot aircraft per mission did not affect the number of aircraft killed or hit by a Chaparral unit (see table 3). The number of aircraft hit in the ten-plane mission was the same as the number hit in the two plane mission. Number of missiles fired was also the same for the two missions. The maximum and minimum number of aircraft hit in any one sample was also the same for the ten aircraft test vs. the two-aircraft test. The code is structured so that only one ADA weapon type per unit will fire at a mission. After firing, the game waits a minimum time to fire another missile. The main advantage to having several weapon systems per unit is that reload times will not constrain the attrition results.

(3) The total number of fixed-wing aircraft hit in the 10-sample set by a Hawk unit did increase from 20 to 25 aircraft when the number of aircraft in the mission was increased from two

to four (see table 3). We believe this is a significant increase because the other parameters, such as average number of rounds fired per engagement and maximum number of aircraft hit, also increased when the mission size was increased.

(4) These results from the tests on mission size indicate that helicopters are played differently from fixed-wing aircraft regarding effect of mission size on attrition from ADA units. Helicopter attrition from the SA-14, a visual weapon, doubled when the mission size doubled. In the case of fixed wing, attrition from a visual weapon did not increase when the mission size was increased, but attrition did slightly increase when a radar-guided weapon was tested against a larger mission size.

c. Effect of altitude on helicopter and fixed-wing attrition.

(1) Helicopters flying at 200 feet have a better chance of surviving than those flying NOE (see table 2). This holds true for both Red and Blue helicopters. We believe this lower attrition for the higher altitudes is a result of two different effects as follows:

(a) The speed increase given to helicopters flying at higher than NOE altitudes. Fewer ADA rounds are fired at the higher flying helicopters because they are flying faster.

(b) The ineffectiveness of the range degrader bands that should decrease ADA fire at NOE altitudes.

(2) Varying the altitude within the bounds we set for the study showed some effect on fixed-wing attrition. An A-10 mission flying at 50 feet MSL suffers less damage from an SA-13 than a mission flying at 200 feet MSL. This is due to the range degradation made for the low altitude. The SA-13 fires only one round per engagement when the plane is flying at 50 feet MSL compared to firing two rounds when the plane is flying at 200 feet MSL. Increasing the Frogfoot mission's altitude from 200 to 500 feet MSL had no effect on attrition from a Stinger unit. This was the expected outcome since the data base Pk remains the same from 0 to 500 feet altitude and no range degradation occurs for this altitude increase. Increasing the Frogfoot mission's altitude from 200 to 1000 feet had no measurable effect on the Hawk's lethality. We believe this was because the Hawk was already hitting 100 percent of its targets at 200 feet so there was not much room for improvement by going to a higher altitude band with a higher Pk.

d. Effect of number of weapon systems per ADA unit. Changing the size of the ADA unit to a smaller number of Hawks and Stingers did result in a decrease in attrition of fixed-wing aircraft but not to the extent that it did in JESS 1.0. Table 3 shows these results in the row labeled Hawk.3 and Stinger.3. In these tests the number of ADA weapons per unit was reduced to three Hawks and three Stingers. Previous tests contain six Hawks or nine Stingers per ADA unit. In JESS 1.0, decreasing the number of Hawks to one-half resulted in half the attrition to aircraft compared to the Hawk ADA unit in its original configuration of six Hawks. In JESS 1.1, decreasing the number of Hawks by half resulted in only a 20 percent decrease in attrition of aircraft. Decreasing the number of Stinger units to one-third the original number resulted in a 33 percent decrease in attrition rate in JESS 1.1. In JESS 1.0, this would have caused a 67 percent decrease in attrition.

(1) The guns such as the ZSU-23-4 and the Vulcan are significantly affected by reduction of number of guns per unit since the total number of rounds fired per salvo is dependent upon the number of guns in the unit. See paragraph 9g. for further discussion of this point.

(2) We can explain the decreased attrition for the Stinger.3 test because the average number of missiles fired decreased when the number of Stinger missiles per unit was reduced. The attrition from the Hawk.3 tests decreased because the minimum number of missions hit by Hawk.3 decreased from two to zero. Hawk.3 tests entirely missed hitting one air mission and had one less total destruction of an air mission than did the tests with six Hawk systems.

(3) In summary, JESS 1.1 is not as sensitive to reduction of ADA missile systems per unit as was JESS 1.0. JESS 1.1 is still very sensitive to changes in the number of guns in the ADA unit.

e. Effect of type of aircraft.

(1) The test results from the JESS 1.1 tests show lower attrition for the F-16s than for the A-10s. One reason is the F-16 is a faster aircraft and the SA-11 ADA does not fire as many rounds at the F-16 as it does the A-10. The F-16 also has lower Pk values assigned to it for each ADA system than does the A-10.

(2) If Pk values for the JESS 1.1 data base were developed by taking into consideration the aircraft's speed, then JESS 1.1 methodology is assessing the contribution of speed on aircraft vulnerability twice. The variable for speed controls how long the aircraft is within range of the ADA weapon and how many salvos will be fired. Faster flying aircraft take fewer shots and accrue less attrition as seen from the helicopter tests in this report. Helicopters fly faster at 200 feet than at NOE altitudes. Table 2 shows that helicopters flying 200 feet received fewer rounds than helicopters flying NOE.

f. Effect of changing the range on attrition.

(1) Changing the range of the ADA weapon may affect attrition if the range change affects the number of salvos fired by the weapon. Changing the number of salvos fired during an engagement is similar to changing the number of tries the ADA unit has to shoot the aircraft. If the system can have more than one try at hitting the aircraft, the probability of a successful hit will increase as the number of tries increases. Even though a weapon system may have a low Pk (remember Pk means probability of hit in JESS), the overall probability of at least one successful hit may become large if the weapon system has the opportunity to fire multiple salvos.

(2) All the above discussion simply applies what we know about the binominal distribution and the probability of a successful hit given a number of tries and given the probability of a success with just one try. Figure 1 is presented to help illustrate this point. Each line shows the overall probability of success given a single shot hit probability (Pk) and N number of tries. From this graph, one sees that a change in range may or may not have a linear effect upon attrition. If the Pk is less than 0.14, the effects of increasing the number of tries tends to be linear. The higher the Pk, the less linear are the effects of increasing the number of tries.

(3) The methodology in JESS 1.1 looks ahead to see at what time an aircraft will enter a radar detection circle or an ADA weapon's circle given its input flight order. These event times are sorted in a cue and the process "goes to sleep" until the first of the event times occurs. The game checks to make sure there still exists a capable radar or ADA weapon to detect or shoot at the aircraft. If so, the detection process or the ADA engagement process begins. If the aircraft is within range of an ADA unit, a salvo is fired, provided the weapon is loaded and all the preconditions for fire are met. The ADA unit can refire after a minimum wait of 15 seconds if the air mission is still within range and all preconditions for firing are met. An air mission flying 390 knots would travel approximately three km in a 15-second interval so an ADA weapon with a range over three km could fire a second salvo after a 15-second wait period.

(4) One cannot predict that for every three-km range change another salvo will be fired because the wait time for each ADA weapon is also dependent upon a data base value called "wait time." All ADA weapons have at least a 15-second wait time because that number is "hard wired" into the code to prevent the attrition routine from becoming stuck in an infinite loop.

(5) Any increase in firing range will be limited by the weapon system's detection range. A Stinger is a visual detection weapon. The limit on the detection range for a Stinger is presently set to eight km. Increasing the Stinger's range to ten km in the data base would result in no firing range increase.

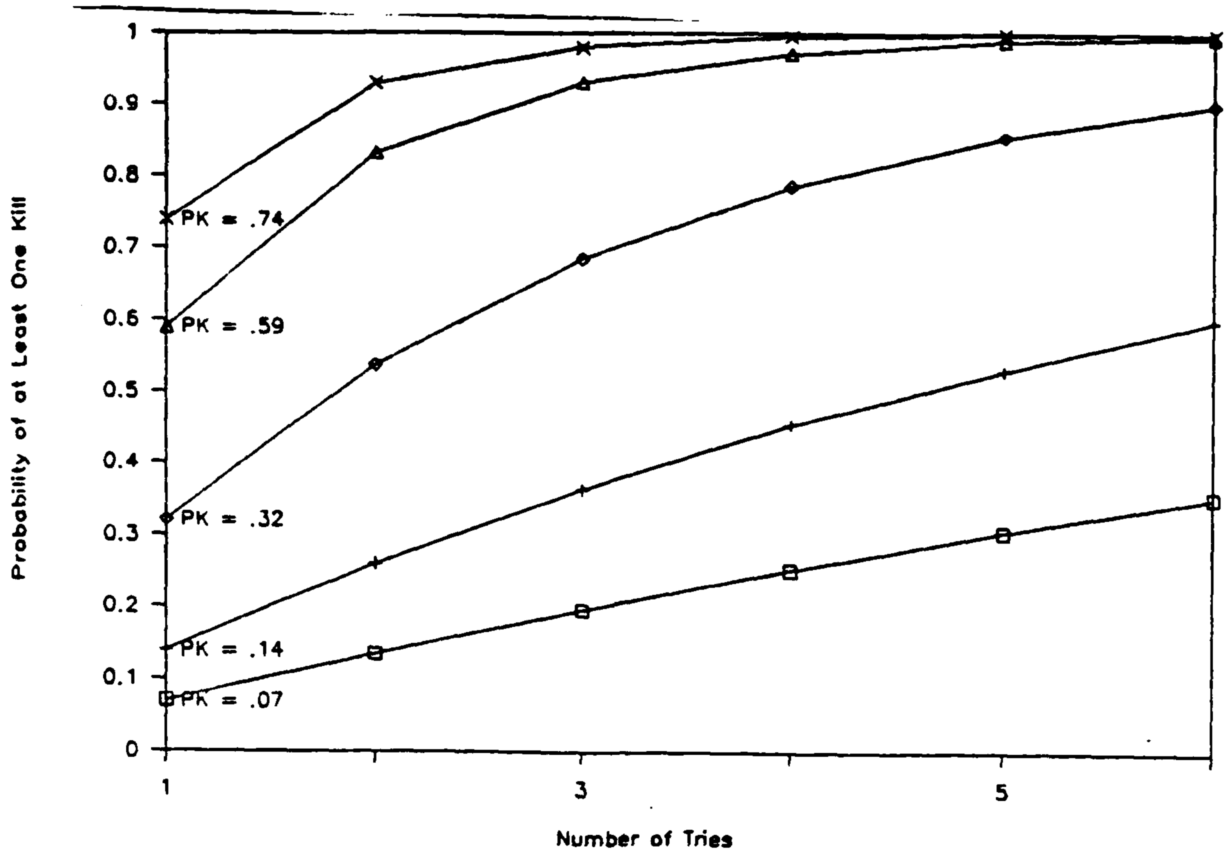

Figure 1. Probability of kill vs. number of tries

g. Effect of changing the number of rounds per burst from guns. For the ADA guns, such as Vulcan or the ZSU-23-4, there is a data base variable called number.rounds.per.burst. The actual number of rounds fired at an aircraft is a function of this data base value. The methodology for guns is that all guns shoot at the same target simultaneously. Therefore, the number of rounds per salvo is the product of the number of guns times the data base variable number.rounds.per.burst.

(1) Table 5 presents results from Vulcan and ZSU-23-4 tests that show the effect of changing the burst rate in the data base on the average attrition to helicopters. The last two columns in table 5 show the actual percent hit from averaging the 10 replicate runs and the predicted percent hit by using the equation below to estimate the changes in attrition from changing the burst rate. The following equation is used:

1 - (1 - Pk) ** n where
Pk = single shot probability of hit
n = the number of rounds per salvo
(rounds per burst * number guns)

Table 5. Effect of number rounds per burst on attrition

	Burst rate	Pk	Rds./ salvo	no. salvo	No. hit out of 40	% hit actual	% hit predicted
ZSU-23-4 vs.							
AH-64 (4) NOE	15	0.0014	60	8	3	0.08	0.08
	30	0.0014	120	8	5	0.13	0.16
Vulcan vs.							
Hind (4) NOE	30	0.0014	120	4	5	0.13	0.16
	60	0.0014	240	4	8	0.20	0.29
	270	0.0014	1080	4	33	0.83	0.78
	100	0.0007	400	4	5	0.13	0.24
	200	0.0007	800	4	17	0.43	0.43

(2) Figure 2 was generated using the above equation to show how attrition is dependent upon number of rounds per burst and the single shot probability of hit (Pk). Changing the number of rounds per burst by decreasing the number of guns in a unit will have a significant effect on attrition by the guns. Normally four ZSU-23-4 will be located in a unit. Figure 2 helps predict how much attrition will decrease if the unit loses one or more of its guns.

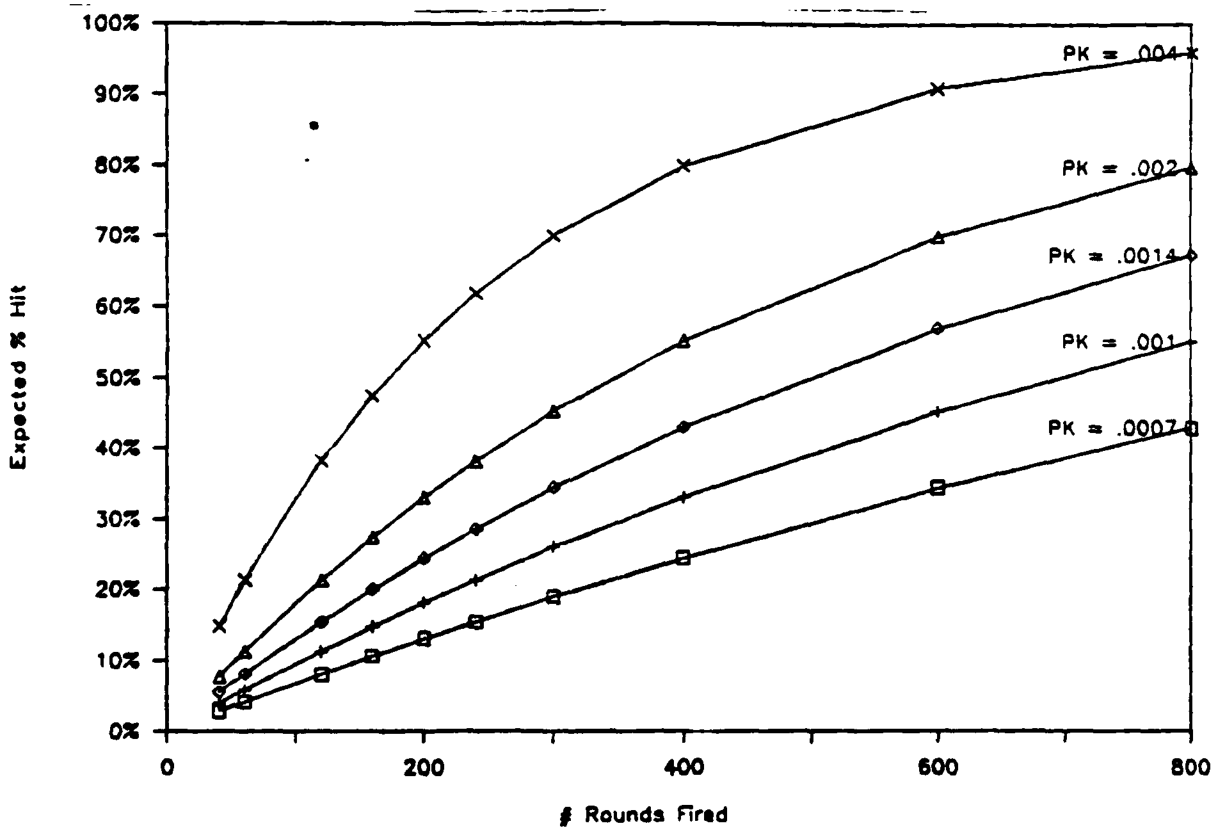

Figure 2. Vulcan and ZSU-23-4: rounds vs. percent hit

(3) The predicted values agree well with the test results except for the 100-round burst from the Vulcan. This test result seems too low given other test results. We have no explanation for this one unexpected result.

(4) The test results show firing four salvos vs. eight salvos did not have a significant effect upon attrition. The main effect on attrition came from changing the rounds per burst and not the range of the weapon system that controls the number of salvos fired. Figure 1 shows that the slope of the curve flattens out as the number of tries for a successful hit increases. The number of salvos fired by the Vulcan and ZSU-23-4 was already high, four for the Vulcan and eight for the ZSU, so we may be beyond the point where changing the number of salvos influences the outcome significantly.

h. Effect of changing the Pk. Table 5 and figure 2 can be used to examine the effect of changing the gun's Pk in the data base. Changing the Pk has a roughly linear effect on resulting attrition. To test the effect of reducing the Pk on missile performance, the Pk of the Chaparral was reduced from 0.5 to 0.25, and the resulting attrition was half. The Stinger Pk was reduced from 0.3 to 0.15, and the resulting attrition was half. All other parameters were held constant in this test. If the range and Pk are both changed. the results may not be linear. Refer to paragraph 9f where effect of range is discussed.

10. Conclusions. In general, we cannot conclude that ADA is performing according to any acceptable standards. Comparing the JESS 1.1 results to the VIC benchmark published in Technical Memorandum TRAC-F-TM-1388, the majority of the weapons we tested were far too lethal. Changes to the data base could correct some problems. Other problems require a code change. Following are specific conclusions classed according to whether the conclusion relates to a data base change, a code change, or a gamer input option.

a. Data base changes.

(1) Comparable Red and Blue weapon systems such as Stinger and SA-14 are not performing comparably in attrition of helicopters or fixed-wing aircraft. This is because their data base Pk values are very different.

(2) The Vulcan and the ZSU-23-4 should not be as lethal as they are against helicopters or fixed wing. One problem is the number of rounds they fire per burst at the target is not the data base value for rounds.per.burst but rather, the product of this data base value times the number of guns in the ADA unit.

(3) Stinger and Chaparral attrition rates for both fixed wing and helicopters are too high. The Chaparral should not be firing at helicopters flying NOE.

(4) SA-11 and Hawk attrition rates are too high. Their Pks need to be lowered.

(5) Patriot, SA-13, and SA-14 attrition is acceptable according to previous benchmark tests with VIC 6.3 excursion results used to benchmark JESS 1.0.

(6) Changing the weapon system's range can greatly affect attrition from that system if the range change affects the number of salvos fired per engagement. Systems with a low Pk and a long range can still have a high attrition rate due to the large number of tries it has to hit the target. As the Pk increases, changing the range has less of an effect on resulting attrition. Also, if the number of tries (corresponding to the number of salvos) is already greater than four, changing the range will have less of an effect on attrition.

(7) Changing the number of rounds per burst from the guns has a nonlinear but predictable effect on attrition.

(8) Changing the weapon system's Pk directly affects attrition from the weapon. The effect is dependent upon how many tries the weapon system has to hit the target. The more tries, the less will be the impact from changing the Pk.

b. Code changes.

(1) JESS 1.1 first release code (referred to as build no. 15 by JPL) is producing some unintended helicopter attrition results. According to the documentation in the SDDL code and the data base, some ADA weapons, such as the SA-11, SA-13, Hawk, and Chaparral, should not be shooting at helicopters flying NOE, yet our results showed these weapon systems were major killers of helicopters flying NOE.

(2) Helicopters are less vulnerable flying at 200 feet above ground level (AGL) than at NOE altitude. This is an incorrect representation that results from giving the helicopters a large speed increase when they are flying above NOE altitudes. This speed increase is controlled by the code and is not a data base variable.

(3) The number of guns in the ADA unit significantly affects the attrition from the weapon system since the total rounds fired at a target per salvo is a function of the number of guns in the unit. In the case of missiles, the number fired per salvo is not dependent upon the number of weapon systems in the unit, but upon a data base value unique for that type system. There is a small impact on attrition when the number of missile systems in the unit is reduced if readiness of the weapon system becomes the limiting factor in determining attrition (i.e., the number of missiles fired is constrained due to reload times).

(4) Allowing fixed-wing aircraft orders to use MSL altitudes but requiring the program to select degradation factors based upon AGL altitudes causes a lot of confusion. Gamers think they will be flying at 200 feet above ground when they input the order, but, due to terrain elevation, the mission may fly at a negative altitude. No penalty is assessed for flying at a negative altitude. Some reward is accrued by flying at a negative altitude because certain ADA weapons will not fire if the aircraft is flying at or below NOE and some radars cannot acquire the target below a minimum threshold of 0.15 km. Helicopter orders are always input as AGL altitude so this problem does not occur for army aviation missions.

c. Gamer-controlled input variables.

(1) Size of the mission has an effect on both helicopter and fixed-wing attrition but has the most effect on helicopter attrition.

(2) Effect on attrition from altitude of the aircraft is mostly attributable to effect from Pk since different Pk values are selected according to the aircraft's altitude. In the case of helicopters, altitude affects attrition through selection of Pk by altitude band. Also altitude selects the speed of the helicopter. Helicopters fly faster above NOE altitudes and have reduced exposure to ADA fire due to their increased speed.

11. Recommendations. Based on this work, we recommend that JESS 1.1 ADA not be accepted as validated. The data base needs to be scrubbed, and the obvious inconsistencies between Red and Blue performance for comparable systems need to be corrected.

a. The Pk values for the Stinger, Chaparral, Hawk, and SA-11 need to be degraded by about 50 percent for altitude bands three and four. The number of rounds per burst for the Vulcan and ZSU-23-4 needs to be downgraded to 60 rounds per burst. The Pk for Vulcan and ZSU needs to be degraded to approximately 0.001.

b. We recommend code changes in the following areas.

(1) The range degradation factors are not being applied as intended due to a code problem.

(2) The increase in speed given to helicopters flying above NOE altitudes is producing some unintended results. The code needs to be changed to prevent helicopters from being less vulnerable at 200 feet AGL than at NOE altitudes.

(3) The definition of the ADA altitude bands in the data base is misleading. The data base values are overridden by the code which changes the boundaries on the altitude bands. This is very confusing for people supplying Pk data based upon altitude of the aircraft. Furthermore, the altitude bands for the range

of the aircraft. Furthermore, the altitude bands for the range degrader bands are defined differently from those for the ADA weapons, i.e., instead of band 1 being the highest band it becomes the lowest band, and the values for the bands are ceiling values instead of floor values. Changing the code so there is some consistency in the definition of these bands would greatly aid the people who supply data for these variables.

(4) Fixed-wing mission orders should be input using AGL altitudes instead of MSL altitudes. Use of MSL altitudes allows the aircraft to fly below ground and gives the aircraft an unintended protection from ADA fire since the ranges of the ADA weapons are degraded if the aircraft are flying below NOE altitudes.

APPENDIX A

REFERENCES

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